one studying the subject from a scientific as well as economic point of view. Mention is made of beds of white pulverulent silica, which when mixed with clay has been used in the manufacture of a paint.

WE have received from the Geological Survey of Canada, Part I of a "Catalogue of Canadian Birds," by Mr. J. Macoren, dealing with water-birds, gallinaceous birds, and pigeons.

THE third volume of Prof. G. O. Sars's "Account of the Crustacea of Norway," dealing with the anomalous group Cumacea, is in course of publication by the Bergen Museum. Parts v. and vi., devoted to the Diastylidæ, have just been issued.

PART 10 of Memoir III. of the Australian Museum, Sydney, on "The Atoll of Funafuti" has now been issued. It is the concluding part of the memoir, and contains lists of the contributors and plates, and an index to the whole work.

MESSRS. ISENTHAL AND CO., have issued a revised edition of their list of apparatus and accessories for work with Röntgen rays. Particular attention is given by this firm to the design and construction of instruments for radiographic work, and any one contemplating an installation for this purpose will find the list just issued well worth examination.

THE additions to the Zoological Society's Gardens during the past week include a Patas Monkey (*Cercopithecus patas*, ♀) from West Africa, presented by Mr. W. B. Davidson Houston; a Rhesus Monkey (*Macacus rhesus*) from India, presented by Mrs. Heigham; a Common Marmoset (*Hapale jacchus*) from South-east Brazil, presented by Mrs. Alexander Grant; two Grey-headed Love-Birds (*Agapornis cana*) from Madagascar, presented by Mrs. Harry Blades; a Cuckoo (*Cuculus canorus*), European, presented by Mr. L. W. Wiglesworth; an Entellus Monkey (*Semnopithecus entellus*, ♀) from India, a —— Bear (*Ursus*, sp. inc.) from Kuldja, a Himalayan Snow Partridge (*Tetrogallus himalayensis*) from the Himalayas, two Brazilian Tortoises (*Testudo tabulata*) from South America, deposited; a Sharp-nosed Badger (*Meles leptorhynchus*) from China, a Rough Fox (*Canis rudis*) from South America, purchased; a Little Bittern (*Ardetta minuta*), European, received in exchange; a Brindled Gnu (*Connochoetes taurina*, ♀), an Altai Deer (*Cervus eustephanus*), born in the Gardens.

RHYTHMS AND GEOLOGIC TIME.[1]

THE subject to which I shall invite your attention this evening is by no means novel, but might better be called perennial or recurrent; for the problem of our earth's age seems to bear repeated solution without loss of vigour or prestige. It has been a marked favourite, moreover, with presidents and vice-presidents, retiring or otherwise, when called upon to address assemblies whose fields of scientific interest are somewhat diverse—for the reason, I imagine, that while the specialist claims the problem as his peculiar theme of study, he feels that other denizens of the planet in question may not lack interest in the early lore of their estate.

The difficulty of the problem inheres in the fact that it not only transcends direct observation but demands the extrapolation or extension of familiar physical laws and processes far beyond the ordinary range of qualifying conditions. From whatever side it is approached the way must be paved by postulates, and the resulting views are so discrepant that impartial onlookers have come to be suspicious of these convenient and inviting stepping stones.

In giving brief consideration to each of the more important ways by which the problem of the earth's age has been ap-

proached, I shall mention first those which follow the action of some continuous process, and afterward those which depend on the recognition of rhythms.

The earliest computations of geologic time, as well as the majority of all such computations, have followed the line of the most familiar and fundamental of geological processes. All through the ages the rains, the rivers and the waves have been eating away the land, and the product of their gnawing has been received by the sea and spread out in layers of sediment. These layers have been hardened into rocky strata, and from time to time portions have been upraised and made part of the land. The record they contain makes the chief part of geologic history, and the groups into which they are divided correspond to the ages and periods of that history. In order to make use of these old sediments as measures of time, it is necessary to know either their thickness or their volume, and also the rate at which they were laid down. As the actual process of sedimentation is concealed from view, advantage is taken of the fact that the whole quantity deposited in a year is exactly equalled by the whole quantity washed from the land in the same time, and measurements and estimates are made of the amounts brought to the sea by rivers and torn from the cliffs of the shore by waves. After an estimate has been obtained of the total annual sedimentation at the present time, it is necessary to assume either that the average rate in past ages has been the same or that it has differed in some definite way.

At this point the course of procedure divides. The computer may consider the aggregate amount of the sedimentary rocks, irrespective of their subdivisions, or he may consider the thicknesses of the various groups as exhibited in different localities. If he views the rocks collectively, as a total to be divided by the annual increment, his estimate of the total is founded primarily on direct measurements made at many places on the continents, but to the result of such measurements he must add a postulated amount for the rocks concealed by the ocean, and another postulated amount for the material which has been eroded from the land and deposited in the sea more than once.

If, on the other hand, he views each group of rocks by itself, and takes account of its thickness at some locality where it is well displayed, he must acquire in some way definite conceptions of the rates at which its component layers of sand, clay and limy mud were accumulated, or else he must postulate that its average rate of accretion bore some definite ratio to the present average rate of sedimentation for the whole ocean. This course is, on the whole, more difficult than the other, but it has yielded certain preliminary factors in which considerable confidence is felt. Whatever may have been the absolute rate of rock building in each locality, it is believed that a group of strata which exhibits great thickness in many places must represent more time than a group of similar strata which is everywhere thin, and that clays and marls, settling in quiet waters are likely to represent, foot for foot, greater amounts of time than the coarser sediments gathered by strong currents; and studying the formations with regard to both thickness and texture, geologists have made out what are called *time ratios*—series of numbers expressing the relative lengths of the different ages, periods and epochs. Such estimates of ratios, when made by different persons, are found to vary much less than do the estimates of absolute time, and they will serve an excellent purpose whenever a satisfactory determination shall have been made of the duration of any one period.

Reade has varied the sedimentary method by restricting attention to the limestones, which have the peculiarity that their material is carried from the land in solution; and it is a point in favour of this procedure that the dissolved burdens of rivers are more easily measured than their burdens of clay and sand.

An independent system of time ratios has been founded on the principle of the evolution of life. Not all formations are equally supplied with fossils, but some of them contain voluminous records of contemporary life; and when account is taken of the amount of change from each full record to the next, the steps of the series are found to be unequal in magnitude. Though there is no method of precisely measuring the steps, even in a comparative way, it has yet been found possible to make approximate estimates, and these in the main lend support to the time ratios founded on sedimentation. They bring aid also at a point where the sedimentary data are weak, for the earliest formations are hard to classify and measure. It is true that these same formations are almost barren of fossils, but biological inference does not therefore stop. The oldest known fauna,

the Eocambrian, does not represent the beginnings of life, but a well advanced stage, characterised by development along many divergent lines ; and by comparing Eocambrian life with existing life the paleontologist is able to make an estimate of the relative progress in evolution before and after the Eocambrian epoch. The only absolute blank left by the time ratios pertains to an azoic age which may have intervened between the development of a habitable earth crust and the actual beginning of life.

Erosion and deposition have been used also, in a variety of ways, to compute the length of very recent geologic epochs. Thus, from the accumulation of sand in beaches, Andrews estimated the age of Lake Michigan, and Upham the age of the glacial lake Agassiz ; and from the erosion of the Niagara gorge the age of the river flowing through it has been estimated. But while these discussions have yielded conceptions of the nature of geological time, and have served to illustrate the extreme complexity of the conditions which affect its measurement, they have accomplished little toward the determination of the length of a geologic period ; for they have pertained only to a small fraction of what geologists call a period, and that fraction was of a somewhat abnormal character.

Wholly independent avenues of approach are opened by the study of processes pertaining to the earth as a planet, and with these the name of Kelvin is prominently associated.

As the rotation of the earth causes the tides, and as the tides expend energy, the tides must act as a brake, checking the speed of rotation. Therefore the earth has in the past spun faster than now, and its rate of spinning at any remote point of time may be computed. Assuming that the whole globe is solid and rigid, and that the geologic record could not begin until that condition had been attained, there could not have been great checking of rotation since consolidation. For if there had been, it would have resulted in the gathering of the oceans about the poles and the baring of the land near the equator, a condition very different from what actually obtains. This line of reasoning yields an obscure outer limit to the age of the earth.

On the assumption that the globe lacks something of perfect rigidity, G. H. Darwin has traced back the history of the earth and the moon to an epoch when the two bodies were united, their separation having been followed by the gradual enlargement of the moon's orbit and the gradual retardation of the earth's rotation ; and this line of inquiry has also yielded an obscure outer limit to the antiquity of the earth as a habitable globe.

One of the most elaborate of all the computations starts with the assumption that at an initial epoch, when the outer part of the earth was consolidated from a liquid condition, the whole body of the planet had approximately the same temperature ; and that as the surface afterward cooled by outward radiation there was a flow of heat to the surface by conduction from below. The rate of this flow has diminished from that epoch to the present time according to a definite law, and the present rate, being known from observation, affords a measure of the age of the crust. The strength of this computation lies in its definiteness and the simplicity of its data ; its weakness in the fact that it postulates a knowledge of certain properties of rock—namely, its fusibility, conductivity and viscosity—when subjected to pressures and temperatures far greater than have ever been investigated experimentally.

A parallel line of discussion pertains to the sun. Great as is the quantity of heat which that incandescent globe yields to the earth, it is but a minute fraction of the whole amount with which it continually parts, for its radiation is equal in all directions, and the earth is but a speck in the solar sky. On the assumption that this immense loss of heat is accompanied by a corresponding loss of volume, the sun is shrinking at a definite rate, and a computation based on this rate has told how many millions of years ago the sun's diameter should have been equal to the present diameter of the earth's orbit. Manifestly the earth cannot have been ready for habitation before the passage of that epoch, and so the computation yields a superior limit to the extent of geologic time.

Before passing to the next division of the subject—the computations based on rhythms—a few words may be given to the results which have been obtained from the study of continuous processes. Realising that your patience may have been strained by the kaleidoscopic character of the rapid review which has seemed unavoidable, I shall spare you the recitation of numerical

details, and merely state in general terms that the geologists, or those who have reasoned from the rocks and fossils, have deduced values for the earth's age very much larger than have been obtained by the physicists, or those who have reasoned from earth cooling, sun cooling and tidal friction. In order to express their results in millions of years, the geologist must employ from three to five digits, while the physicists need but one or two. When these enormous discrepancies were first realised, it was seen that serious errors must exist in some of the observational data, or else in some of the theories employed ; and geologists undertook with zeal the revision of their computations, making as earnest an effort for reconciliation as had been made a generation earlier to adjust the elements of the Hebrew cosmogony to the facts of geology. But after rediscussing the measurements and readjusting the assumptions so as to reduce the time estimates in every reasonable way—and perhaps in some that were not so reasonable—they were still unable to compress the chapters of geologic history between the narrow covers of physical limitation ; and there the matter rests for the present.

The rocks which were formed as sediments show many traces of rhythm Some are composed of layers, thin as paper, which alternate in colour, so that when broken across they exhibit delicate banding. In the time of their making there was a periodic change in the character of the mud that settled from the water. Others are banded on a larger scale ; and there are also bandings of texture where the colour is uniform. Many formations are divided into separate strata, as though the process of accretion had been periodically interrupted. Series of hard strata are often separated by films or thin layers of softer material. Strata of two kinds are sometimes seen to alternate through many repetitions. Borings in the delta of the Mississippi show soils and remains of trees at many levels, alternating with river silts. The rock series in which coal occurs are monotonous repetitions of shale and sandstone. Belgian geologists have been so impressed by the recurrence of short sequences of strata that they have based an elaborate system of rock notation upon it.

Passing to still greater units, the large aggregates of strata sometimes called systems show in many cases a regular sequence, which Newberry called a "circle of deposition." When complete it comprises a sandstone or conglomerate, at base, then shale, limestone, shale and sandstone. This sequence is explained as the result of the gradual encroachment, or transgression as it is called, of the sea over the land and its subsequent recession.

In certain bogs of Scandinavia deep accumulations of peat are traversed horizontally by layers including tree stumps in such way as to indicate that the ground has been alternately covered by forest and boggy moss. The broad glaciers of the Ice age grew alternately smaller and larger—or else were repeatedly dissipated and reformed—and their final waning was characterised by a series of halts or partial readvances, recorded in concentric belts of ice-brought drift. Of these belts, called moraines of recession, Taylor enumerates seventeen in a single system.

In explanation of these and other repetitive series incorporated in the structure of the earth's crust, a variety of rhythmic causes have been adduced ; and mention will be made of the more important, beginning with those which have the character of original rhythms.

A river flowing through its delta clogs its channel with sediment, and from time to time shifts its course to a new line, reaching the sea by a new mouth. Such changes interrupt and vary sedimentation in neighbouring parts of the sea. Storms of rain make floods, and each flood may cause a separate stratum of sediment. Storms of wind give destructive force to the waves that beat the shore, and each storm may cause the deposit of an individual layer of sediment. Varying winds may drive currents this way and that, causing alternations in sedimentation.

To explain the forest beds buried in the Mississippi silts it has been suggested that the soft deposits of the delta from time to time settled and spread out under their own weight. Various alternations of strata, and especially those of the Coal measures, have been ascribed to successive local subsidences of the earth's crust, caused by the addition of loads of deposit. It has been suggested also that land undergoing erosion may rise up from time to time because relieved of load, and the character of sediment might be changed by such rising. Subterranean forces, of whatever origin, seemingly slumber while strains are accumulating, and then become suddenly manifest in dislocations and eruptions, and such catastrophes affect sedimentation.

A more general rhythm has been ascribed to the tidal retardation of rotation and the resulting change of the earth's form. If the body of the earth has a rather high rigidity, we should expect that it would for a time resist the tendency to become more nearly spherical, while the water of the ocean would accommodate itself to the changing conditions of equilibrium by seeking the higher latitudes. Eventually, however, the solid earth would yield to the strain and its figure become adjusted to the slower rotation, and then the mobile water would return. Thus would be caused periodic transgressions by the sea, occurring alternately in high and low latitudes.

Another general rhythm has been recently suggested by Chamberlin in connection with the hypothesis that secular variations of climate are chiefly due to variations of the quantity of carbon dioxide in the atmosphere.[1] The system of interdependent factors he works out is too complex for presentation at this time, and I must content myself with saying that his explanation of the moraines of recession involves the interaction of a peculiar atmospheric condition with a condition of glaciation, each condition tending to aggravate the other, until the cumulative results brought about a reaction and the climatic pendulum swung in the opposite direction. With each successive oscillation the momentum was less, and an equilibrium was finally reached.

Few of these original rhythms have been used in computations of geologic time, and it is not believed that they have any positive value for that purpose. Nevertheless, account must be taken of them, because they compete with imposed rhythms for the explanation of many phenomena, and the imposed rhythms, wherever established, yield estimates of time.

The tidal period, or the half of the lunar day, is the shortest imposed rhythm appealed to in the explanation of the features of sedimentation. It is quite conceivable that the bottom of a quiet bay may receive at each tide a thin deposit of mud which could be distinguished in the resulting rock as a papery layer or lamina. If one could in some way identify a rock thus formed, he might learn how many half-days its making required by counting its laminæ, just as the years of a tree's age are learned by counting its rings of growth.

The next imposed rhythm of geologic importance is the year. There are rivers, like the Nile, having but one notable flood in each year, and so depositing annual layers of sediment on their alluvial plains and on the sea beds near their mouths. Where oceanic currents are annually reversed by monsoons, sedimentation may be regularly varied, or interrupted, once a year. Streams from a glacier cease to run in winter, and this annual interruption may give a definite structure to resulting deposits. It is therefore probable that some of the laminæ or strata of rocks represent years, but the circumstances are rarely such that the investigator can bar out the possibility that part of the markings or separations were caused by original rhythms of unknown period.

The number of rhythms existing in the solar system is very large, but there are only two, in addition to the two just mentioned, which seem competent to write themselves in a legible way in the geologic record. These are the rhythms of precession and eccentricity.

Because the earth's orbit is not quite circular and the sun's position is a little out of the centre, or is eccentric, the two hemispheres into which the earth is divided by the equator do not receive their heat in the same way. The northern summer, or the period during which the northern hemisphere is inclined toward the sun, occurs when the earth is farthest from the sun, and the northern winter occurs when the earth is nearest to the sun, or in that part of the orbit called perihelion. These relations are exactly reversed for the southern hemisphere. The general effect of this is that the southern summer is hotter than the northern, and the southern winter is colder than the northern. In the southern part of the planet there is more contrast between summer and winter than in the northern. The sun sends to each half the same total quantity of heat in the course of a year, but the difference in distribution makes the climates different. The physics of the atmosphere is so intricate a subject that meteorologists are not fully agreed as to the theoretical consequences of these differences of solar heating, but it is generally believed that they are important, involving differences in the force of the winds, in the velocity and course of ocean currents, in vegetation, and in the extent of glaciers.

Now, the point of interest in the present connection is that the astronomical relations which occasion these peculiarities are not constant, but undergo a slow periodic change. The relation of the seasons to the orbit is gradually shifting, so that each season in turn coincides with the perihelion; and the climatic peculiarities of the two hemispheres, so far as they depend on planetary motions, are periodically reversed. The time in which the cycle of change is completed, or the period of the rhythm, is not always the same, but averages 21,000 years. It is commonly called the precessional period.[1]

Assuming that the climates of many parts of the earth are subject to a secular cycle, with contrasted phases every 10,500 years, we should expect to find records of the cycle in the sediments. A moist climate would tend to leach the calcareous matter from the rock, leaving an earthy soil behind, and in a succeeding drier climate the soil would be carried away; and thus the adjacent ocean would receive first calcareous and then earthy sediments. The increase of glaciers in one hemisphere would not only modify adjacent sediments directly, but, by adding matter on that side, would make a small difference in the position of the earth's centre of gravity. The ocean would move somewhat toward the weighted hemisphere, encroaching on some coasts and drawing down on others; and even a small change of that sort would modify the conditions of erosion and deposition to an appreciable extent in many localities.

Blytt ascribed to this astronomical cause the alterations of bog and forest in Scandinavia, as well as other sedimentary rhythms observed in Europe; and it has seemed to me competent to account for certain alternations of strata in the Cretaceous formations of Colorado. Croll used it to explain interglacial epochs, and Taylor has recently applied it to the moraines of recession.

The remaining astronomical rhythm of geological import is the variation of eccentricity. At the present time our greatest distance from the sun exceeds our least distance by its thirtieth part, but the difference is not usually so small as this. It may increase to the seventh part of the whole distance, and it may fall to zero. Between these limits it fluctuates in a somewhat irregular way, in which the property of periodicity is not conspicuous. The effect of its fluctuation is inseparable from the precessional effect, and is related to it as a modifying condition. When the eccentricity is large the precessional rhythm is emphasised; when it is small the precessional effect is weak.

The variation of eccentricity is connected with the most celebrated of all attempts to determine a limited portion of geological time. In the elaboration of the theory of the Ice age which bears his name, Croll correlated two important epochs of glaciation with epochs of high eccentricity computed to have occurred about 100,000 and 210,000 years ago. As the analysis of the glacial history progresses, these correlations will eventually be established or disproved, and should they be established it is possible that similar correlations may be made between events far more remote.

The studies of these several rhythms, while they have led to the computation of various epochs and stages of geologic time, have not yet furnished an estimate either of the entire age of the earth or of any large part of it. Nevertheless, I believe that they may profitably be followed with that end in view.

The system of rock layers, great and small, constituting the record of sedimentation, may be compared to the scroll of a chronograph. The geological scroll bears many separate lines, one for each district where rocks are well displayed, but these are not independent, for they are labelled by fossils, and by means of these labels can be arranged in proper relation. In each time line are little jogs—changes in kind of rock or breaks in continuity—and these jogs record contemporary events. A new mountain was uplifted, perhaps, on the neighbouring continent, or an old uplift received a new impulse. Through what Davis calls stream piracy a river gained or lost the drainage of a tract of country. Escaping lava threw a dam across the course of a stream, or some Krakatoa strewed ashes over the land and gave the rivers a new material to work on. The jogs may be faint or strong, many or few, and for long distances the lines may run smooth and straight; but so long as the jogs are irregular they give no clue to time. Here and there, however, the even line will betray a regularly recurring indentation or

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[1] An attempt to frame a working hypothesis of the cause of glacial periods on an atmospheric basis. *Journ. Geol.*, vol. vii., 1899.

[1] Strictly speaking, 21,000 years is the period of the precession of the equinoxes as referred to perihelion; but the perihelion is itself in motion. As referred to a fixed star the precession of the equinoxes has an average period of about 25,700 years.

undulation, reflecting a rhythm and possibly significant of a remote pendulum whose rate of vibration is known. If it can be traced to such a pendulum there will result a determination of the rate at which the chronograph scroll moved when that part of the record was made ; and a moderate number of such determinations, if well distributed, will convert the whole scroll nto a definite time scale.

In other words, if a sufficient number of the rhythms embodied in strata can be identified with particular imposed rhythms, the rates of sedimentation under different circumstances and at different times will become known, and eventually so many parts of geologic time will have become subject to direct calculation that the intervals can be rationally bridged over by the aid of time ratios.

For this purpose there is only one of the imposed rhythms of practical value, namely, the precessional ; but that one is, in my judgment, of high value. The tidal rhythm cannot be expected to characterise any thick formation. The annual is liable to confusion with a variety of original rhythms, especially those connected with storms. The rhythm of eccentricity, being theoretically expressed only as an accentuation of the precessional, cannot ordinarily be distinguished from it. But none of these qualifications apply to the precessional. It is not liable to confusion with the tidal and annual because its period is so much longer. being more than 2000 times that of the annual. It has an eminently practical and convenient magnitude, in that its physical manifestation is well above the microscopic plane, and yet not so large as to prevent the frequent bringing of several examples into a single view. It is also practically regular in period, rarely deviating from the average length by more than the tenth part.

From the greater number of original rhythms it is distinguished, just as from the annual and tidal, by magnitude. The practical geologist would never confuse the deposit occasioned by a single storm, for example, with the sediments accumulated during an astronomical cycle of 20,000 years. But there are other original rhythms, known or surmised, which might have magnitudes of the same general order, and to discriminate the precessional from these it is necessary to employ other characters. Such characters are found in its regularity or evenness of period, and in its practical perpetuity. The diversion of the mouth of a great river, such as the Hoang Ho or the Mississippi, might recur only after long intervals ; but from what we know of the behaviour of smaller streams we may be sure that such events would be very irregular in time as well as in other ways. The intervals between volcanic eruptions at a particular vent or in a particular district may at times amount to thousands of years, but their irregularity is a characteristic feature. The same is true of the recurrent uplifts by which mountains grow, so far as we may judge them by the related phenomena of earthquakes ; and the same category would seem to hold also the theoretically recurrent collapse of the globe under the strains arising from the slowing of rotation. The carbon dioxide rhythm, known as yet only in the field of hypothesis, is hypothetically a running-down oscillation, like the lessening sway of the cradle when the push is no longer given.

But the precessional motion pulses steadily on through the ages like the swing of a frictionless pendulum. Its throb may or may not be caught by the geological process which obtains in a particular province and in a particular era, but whenever the conditions are favourable and the connection is made, the record should reflect the persistence and the regularity of the inciting rhythm.

The search of the rocks for records of the ticks of the precessional clock is an out-of-door work. Pursued as a closet study it could have no satisfactory outcome, because the printed descriptions of rock sequences are not sufficiently complete for the purpose ; and the closet study of geology is peculiarly exposed to the perils of hobby-riding. A student of the time problem cannot be sure of a persistent, equable sedimentary rhythm without direct observation of the characters of the repeated layers. He needs to avail himself of every opportunity to study the series in its horizontal extent, and he should view the local problem of original *versus* imposed rhythm with the aid of all the light which the field evidence can cast on the conditions of sedimentation.

Neither do I think of rhythm seeking as a pursuit to absorb the whole time and energy of an individual and be followed steadily to a conclusion ; but hope rather that it may receive the incidental and occasional attention of many of my colleagues

of the hammer, as other errands lead them among cliffs of bedded rocks. If my suggestion should succeed in adding a working hypothesis or point of view to the equipment of field geologists, I should feel that the search had been begun in the most promising and advantageous manner. For not only would the subject of rhythms and their interpretations be advanced by reactions from multifarious individual experiences, but the stimulus of another hypothesis would lead to the discovery of unexpected meanings in stratigraphic detail.

It is one of the fortunate qualities of scientific research that its incidental and unanticipated results are not unfrequently of equal or even greater value than those directly sought. Indeed, if it were not so there would be no utilitarian harvest from the cultivation of the field of pure science.

In advocating the adoption of a new point of view from which to peer into the mysterious past, I would not be understood to advise the abandonment of old standpoints, but rather to emulate the surveyor, who makes measurement to inaccessible points by means of bearings from different sides. Every independent bearing on the earth's beginning is a check on other bearings, and it is through the study of discrepancies that we are to discover the refractions by which our lines of sight are warped and twisted. The three principal lines we have now projected into the abyss of time miss one another altogether, so that there is no point of intersection. If any one of them is straight, both the others are hopelessly crooked. If we would succeed we should not only take new bearings from each discovered point of vantage, but strive in every way to discover the sources of error in the bearings we have already attempted.

THE RELATION OF STIMULUS TO SENSATION.

NOTHING has done more to place on a scientific footing the discussion of the phenomena which the study of matter and energy presents to the eye of reason, than the establishment of a doctrine of quantitative equivalence. So much oxygen and hydrogen, so much water ; this amount of energy of chemical separation gone, that amount of sensible heat gained. In a similar way, nothing is likely to do more to give support to the hypothesis that sentience or consciousness is a concomitant of certain physiological processes than the establishment of a quantitative relation between stimulus and sensation.

It has, indeed, long been obvious that some general relation of this kind holds good. Increased physical pressure is, within certain limits, increasingly felt ; more light gives a higher degree of visual sensation ; the greater the amplitude of the vibrations of a violin-string the fuller and louder the sound. Such statements are, however, indefinite. We want to know how much the physical increase must be to give just so much increment in sensation. If we double the strength of the stimulus, do we double also the strength of the sensation ? If not, by how much do we increase it ? Ernst Heinrich Weber sought to express the quantitative relation with some exactness ; Gustav Theodor Fechner and other more recent inquirers have built upon the foundations laid by Weber ; and a provisional law of the relation of physical stimulus to felt sensation has gradually gained wide acceptance.

Weber's classical experiments dealt with what is termed the " least observable difference." If, for example, a weight of one pound be laid upon the hand, it gives rise to a sensation of pressure. If, now, an extra ounce be added no difference is felt, nor is the added weight of two or of three ounces perceptible. The sensation is not increased, and then only just perceivably increased, till one-third of a pound is added. This, then, is said to be the least observable difference. We now start afresh with a load of two pounds, and add, as before, one-third of a pound. But there is no observable difference ; nor is there any felt increase in sensation until two-thirds of a pound are added. Starting once more with an initial load of three pounds, we find that neither the addition of one-third, nor that of two-thirds of a pound affords any observable difference in the sensation experienced. A full pound must be added for the increment to be felt. The least observable differences, therefore, are between

$$1 \text{ lb. and } 1 + \tfrac{1}{3} \text{ lb.}$$
$$2 \text{ lb. ,, } 2 + \tfrac{2}{3} \text{ lb.}$$
$$3 \text{ lb. ,, } 3 + \tfrac{3}{3} \text{ lb.}$$

If, then, we extend and generalise the results of such experiments, we find that, within certain limits, to obtain an orderly